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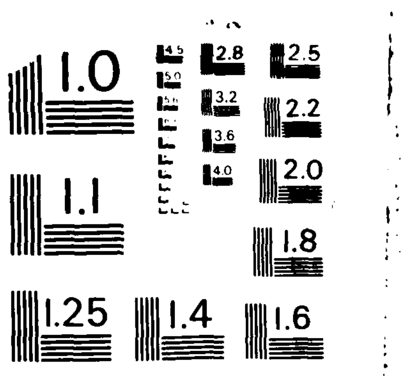

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Abstract

The behavior of fluxons was studied in all-niobium long Josephson Junctions. We have investigated fluctuations due to fluxon motion between bistable states. Such fluctuations show Lorentzian spectra with characteristic times ranging from 10 milliseconds to 1μ-second. We have analyzed instabilities in the current steps of the I-V characteristics in terms of intermittency between periodic solutions and unstable behavior leading to chaos. The effects of boundaries were investigated as to the gain and fluctuations of long Josephson junctions. Ultrasonic radiation was used to study fluxon pinning problems.

Experiments are proposed for the next period. They deal with fundamental questions such as fluctuations, tunneling, and boundary conditions, affecting the performance of the junctions and their applications.

I. Introduction and Goals

In the past 20 years there has been a great deal of activity related to devices known as SQUIDS. A SQUID consists of small Josephson junctions incorporated in a superconducting loop to form an interferometer. The characteristics of such devices are based on flux quantization in the loop. It turns out that another type of device can be fabricated, in the form of a long Josephson junction, where flux quantization occurs inside the junction. Such quantized vortices, called fluxons, can be made to move by a bias current due to the Lorentz force acting on them. Although such a device has not received much attention in the past, it has very interesting properties. Actually the long Josephson junction is the counter part of a semiconductor FET and it is essentially a 3-terminal device. A control line near the junction creates fluxons which can be moved by the bias current through the junction. Such a junction shows great promise for devices because of relative insensitivity to radiation and high speed. Its non-linear quantum mechanical behavior offers a variety of interesting physics problems; also it is a simple model for studying non-linear behavior applicable to a variety of other areas and systems.

The goals of this research are to study the dynamics of fluxons in long Josephson junctions, to investigate the interactions of fluxons with defects, and to find out about their characteristics and limitations. It is important to study these topics since all the devices based on long Josephson junctions depend on the control of fluxon motion. Uncontrolled fluxon motion (noise) is also of interest and hence we have investigated fluctuations in such junctions.

Isolated fluxons behave like particles which are reflected at the open-ended junction ends. This occurs in small applied magnetic fields. The influence of the boundary conditions (at the ends) can lead to cavity resonances resulting in discrete current steps in the I-V curve of the junction. This is the resonant mode and one refers to zero field steps in the I-V curve. In a magnetic field, the reflected fuxons excite plasma oscillations in the junction leading to current steps known as Fiske steps. When many fluxons are packed together by applying a relatively large external field, they behave like electromagnetic waves rather than particles, and their unilateral motion is referred to as "flux-flow". The magnetic field and the bias current must then be adjusted to continuously create fluxons in one end of the junction and absorb fluxons in the other. The phase ϕ behavior of fluxons is determined by a non-linear differential equation of the form

$$-\phi_{xx} + \phi_{tt} + \sin\phi = \eta - \alpha\phi_t + \beta\phi_{xxt} \tag{1}$$

where α is a damping term and β is a surface loss term; η is the bias term, d.c. or a.c.. Of special interest are the interactions of fluxons with the surfaces and boundaries, and with each other, as well as their behavior under d.c. or a.c. drives.

II. Experiments and Results

A. Fluctuations in Long Josephson Junctions

In a Josephson junction critical current fluctuations and flux noise are the main contributions to the overall noise. Critical current fluctuations contribute strongly to the low-frequency noise. If one were to apply a general characterization for most devices their low frequency noise spectral density[1] can be written as:

$$\frac{S_{v(f)}}{V^2} = \frac{2 \times 10^{-3}}{N_c} \frac{1}{f} \tag{2}$$

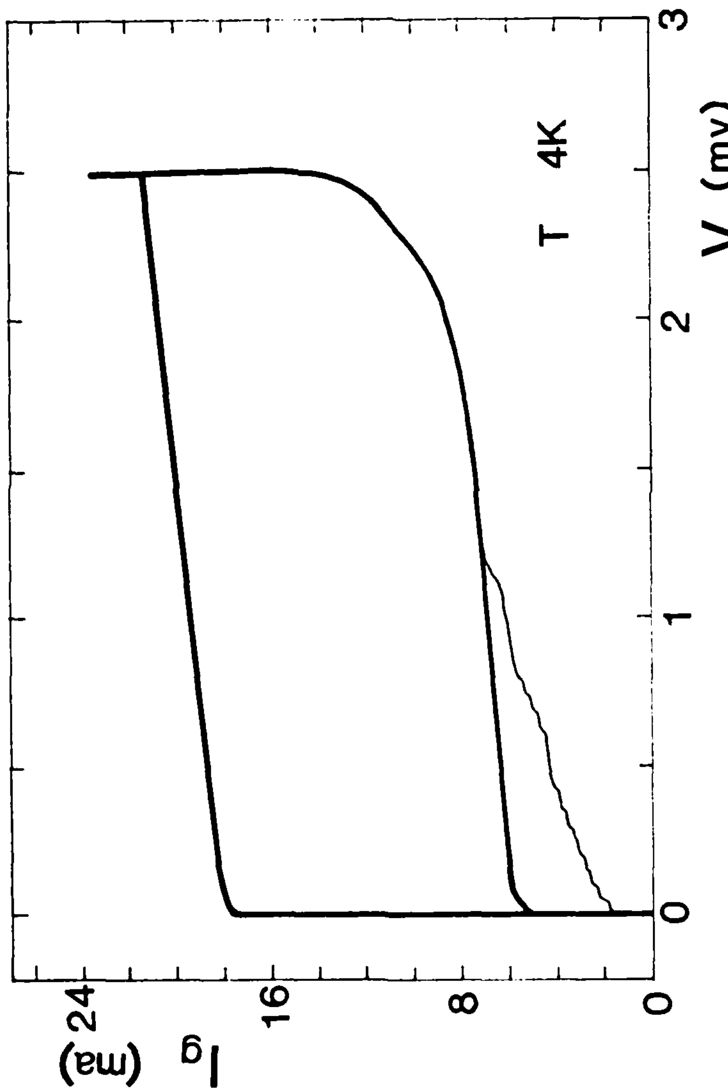

Figure 1a. I-V curve for long junction at different I_s.

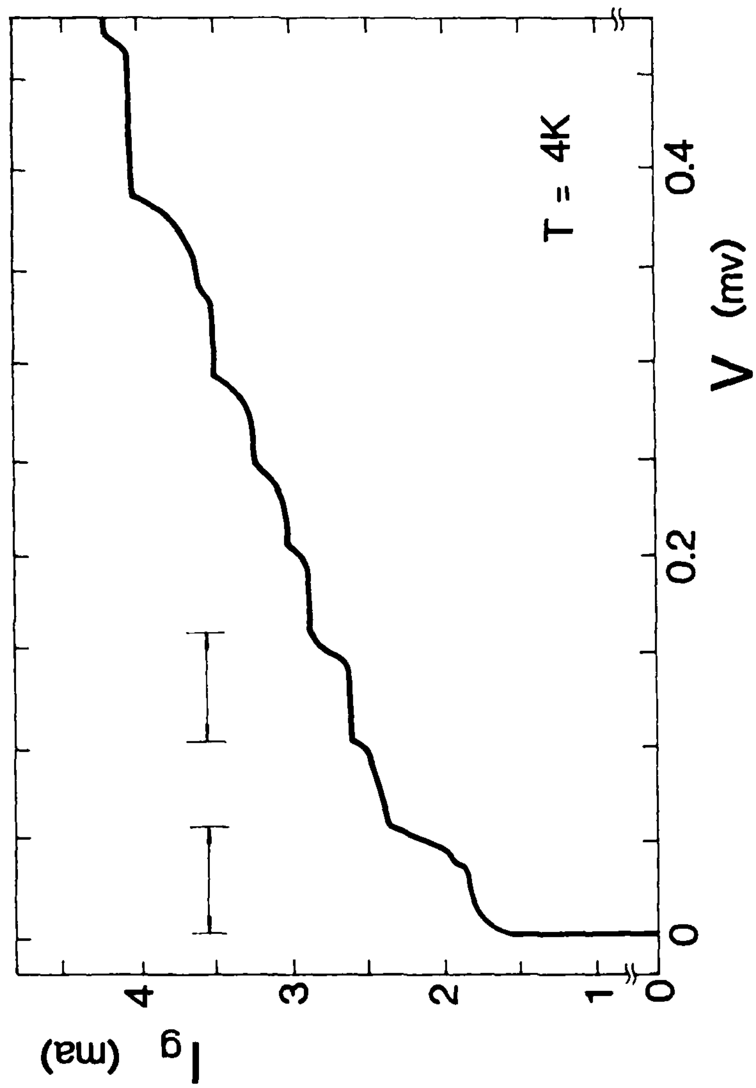

Figure 1b. Details of Fig. 1a in a field produced by I_s.

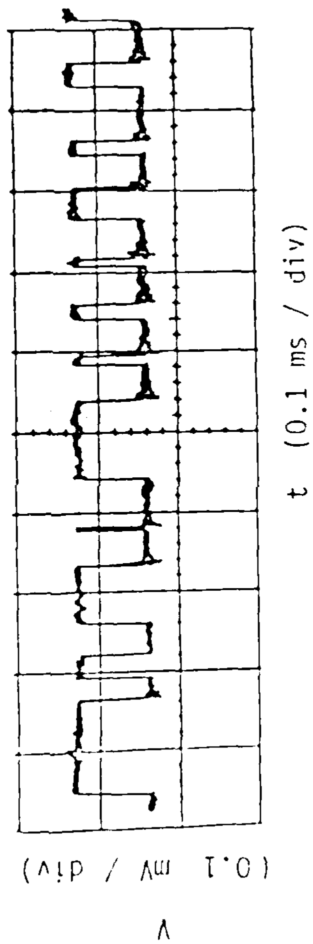

Figure 2. Telegraph noise for junction with characteristics of fig. 1.

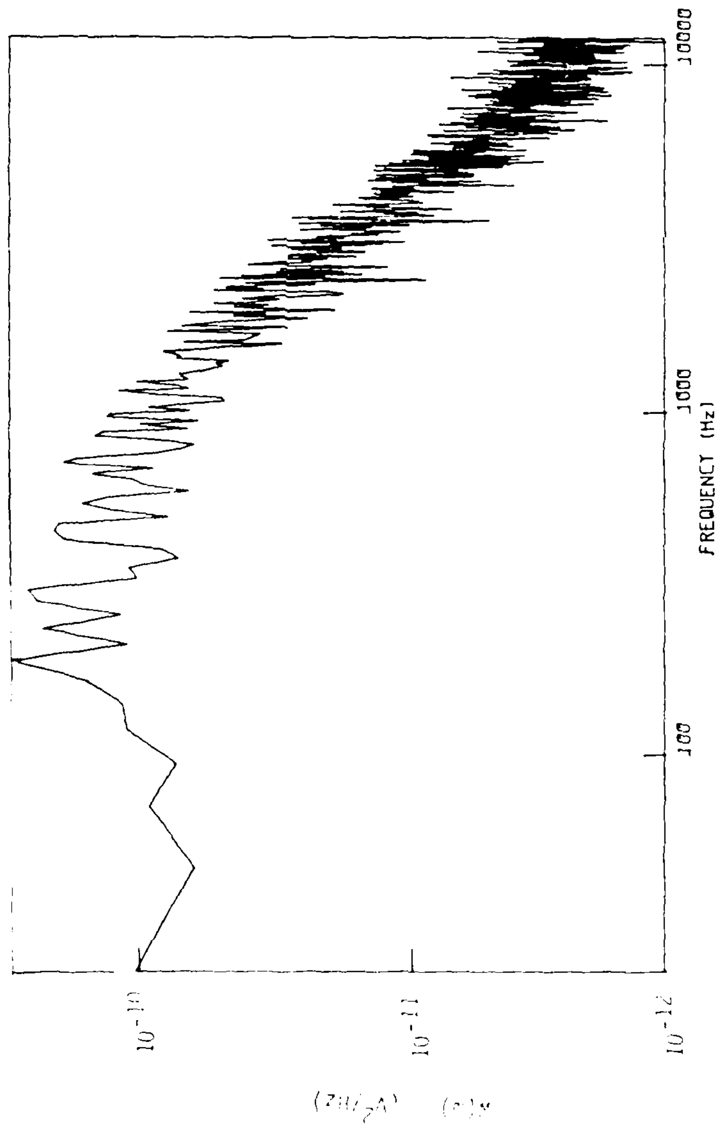

Figure 3. Spectral density for telegraph noise of long junction.

where N_c is the total number of carriers. This demonstrates that small samples have large amounts of 1/f noise. Thus one would expect[2] a small Josephson junction to have more 1/f noise than a long Josephson junction. Indeed we have observed that this is true; the noise scales as 1/area of the junction. To extend our investigation of noise, we have studied the flux motion contribution to the low frequency noise of a long Josephson junction. This has not been investigated before.

Junctions were fabricated with the following dimensions and specifications: 130 μm long, 6 μm wide, 8 injection fingers, top and bottom electrodes were niobium, the junction barrier was $A\ell$-$A\ell_2O_3$-$A\ell$, the current density was 3×10^3 A/cm^2, and the McCumber parameter $\beta_c \simeq 15$.

To investigate the fluxon fluctuations, the junction was biased to a signal current I_s (here around 50 mA) and the I-V curve was recorded. Current steps were observed with a voltage periodicity of 47 μv. When biased on one of the steps, current fluctuations caused the voltage to fluctuate showing a characteristic telegraph type of noise. Figure 1 shows the I-V curve. A typical telegraph noise voltage-time graph is shown in figure 2. The power spectrum of the fluctuations between two current steps can be represented by a Lorentzian distribution of the form

$$S(\omega) = 4\ \bar{V}\ \Delta V\ \tau_o/(1 + \omega^2\ \tau_o^2) \qquad (3)$$

where ΔV is the voltage difference between two adjacent current steps and τ_o is a characteristic time describing transitions up and down between the 2 steps. Our measurements show that τ_o can be in the range of 10^{-6} second to 10^{-2} second depending strongly on the bias conditions. Figure 3 shows a typical spectral density with a characteristic $1/\omega^2$ behavior representing the kinetics of a 2-level system. Indeed a real-time voltage as shown in figure 2 forms a complete time record of the trapping behavior for a fluxon in 2 different states. By measuring the time spent in the up and down voltage states, the lifetime of the 2 trap states was determined. These lifetimes can be varied by the bias conditions and this is shown in figure 4. By adjusting the bias conditions, a 50% duty cycle for the telegraph noise was obtained and we investigated it for different steps on the I-V curve. The characteristic times τ_o obtained for each step depend on the width of the transition in the current steps. Figure 5 shows the definition for this width, ΔI_g. By investigating the telegraph noise in this way for each step, we obtain the interesting results shown in figure 6 where the effect of ΔI_g on τ_o is shown for a wide range of current steps. It clearly shows that as the width of the transition becomes smaller, the lifetime approaches the characteristic time for a fluxon to go across the junction ($\sim 10^{-10}$ seconds). We attribute the long τ_o as measured to possible pinning of a fluxon in the barrier.

This investigation was extended to lower temperatures, below 4 K. The situation is complicated because the critical current increases as the temperature is lowered making it difficult to maintain the same bias conditions. A larger bias current increases the Lorentz force on a fluxon, thus depinning trapped fluxons and reducing τ_o. We have observed this over a rather limited temperature range, 4 K to 3 K.

We have created a situation, by a suitable bias, where a fluxon can hop between 2 states; the amplitude of this hopping is determined by the geometry of the junction. The drive mechanism for this drive could be thermal or quantum mechanical tunneling. It can be viewed as the addition of a random term to the bias current thus exerting a random force on the fluxon. For thermal motion, the important parameter is

$$\gamma_o = \frac{2\pi\ kT}{\phi_o\ I_c} \qquad (4)$$

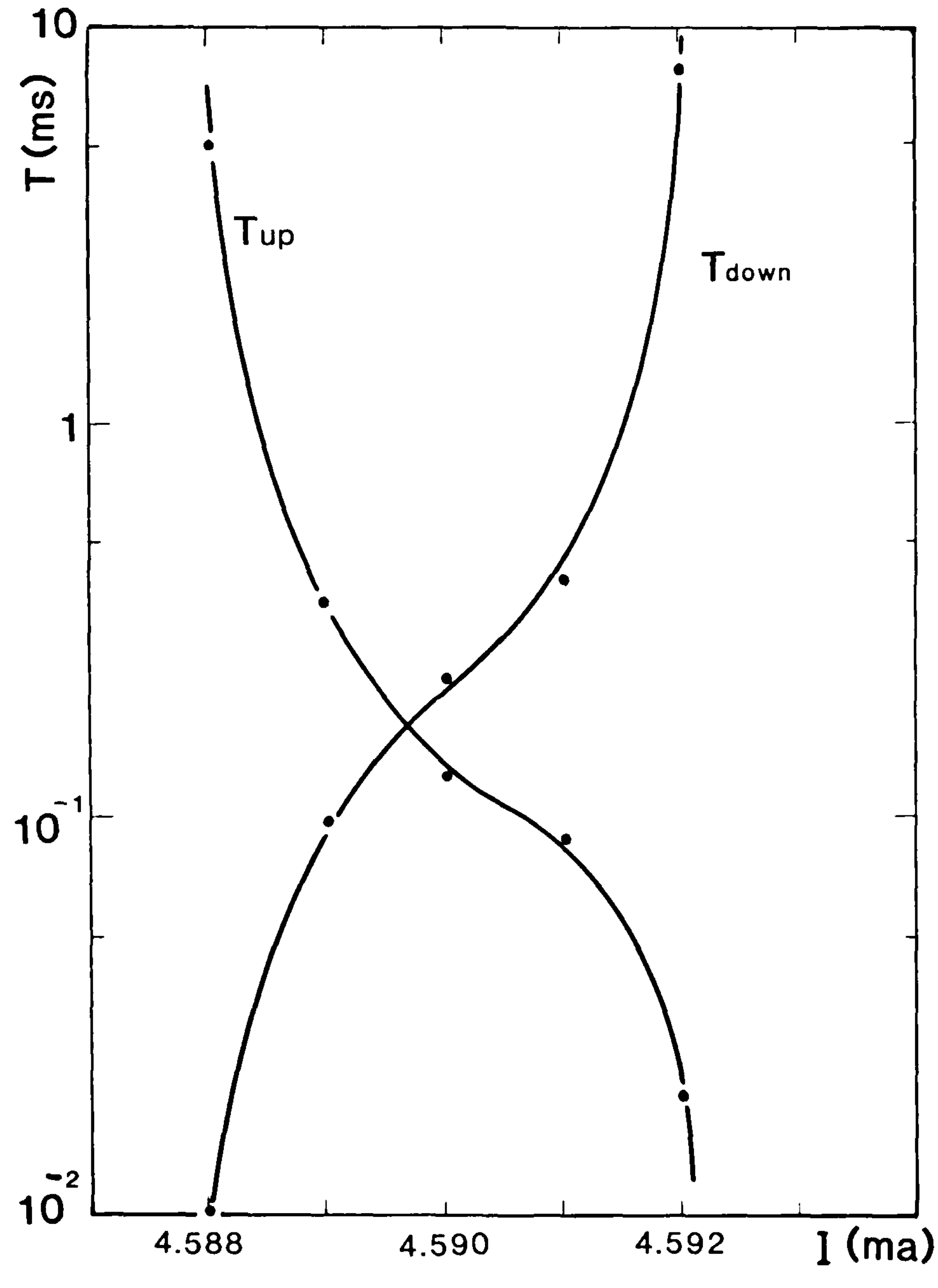

Figure 4. Fluxon lifetime in lower (τ_{down}) and upper (τ_{up}) states on a set of current steps.

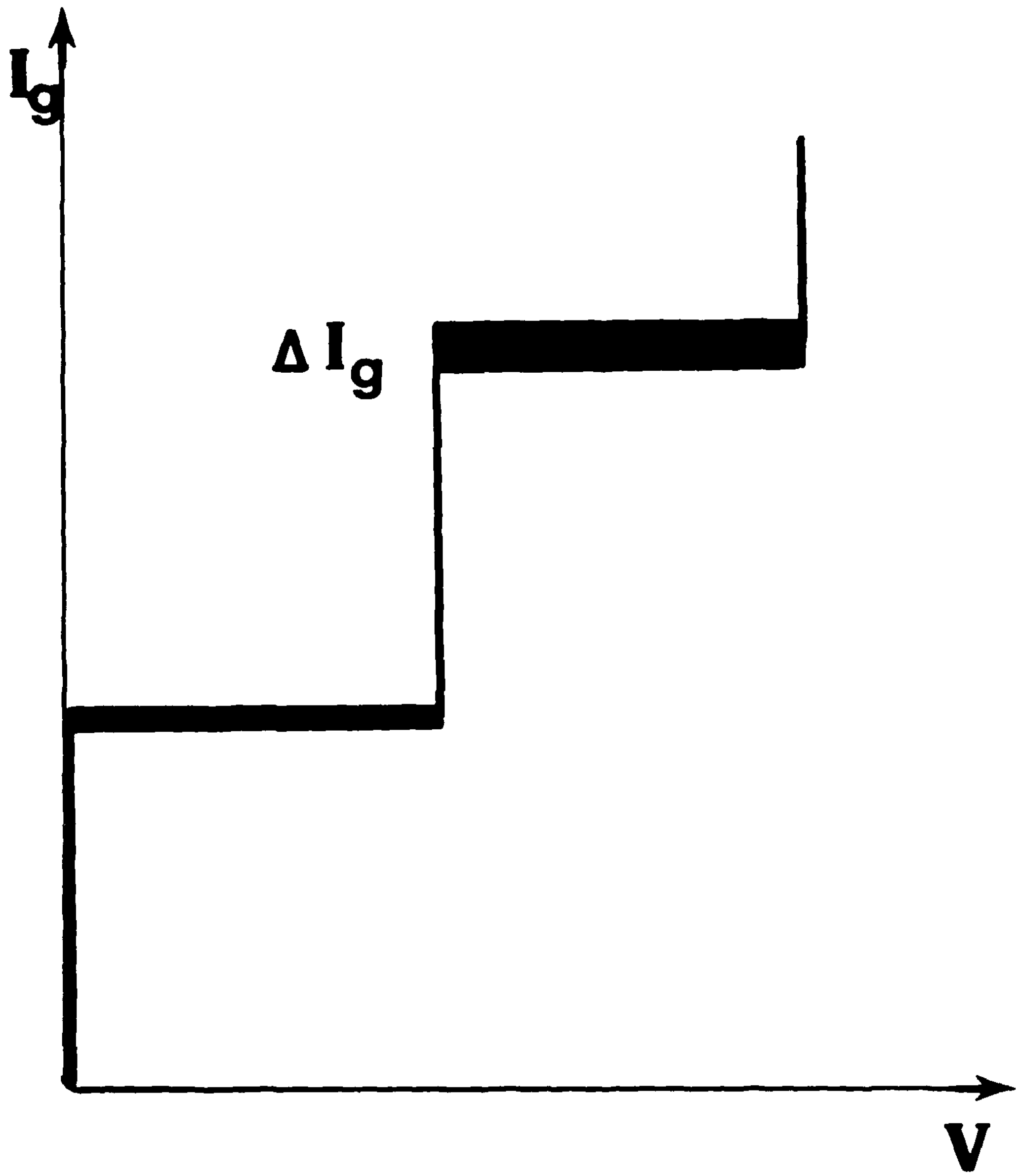

Figure 5. Details of current step where fluctuations were studied.

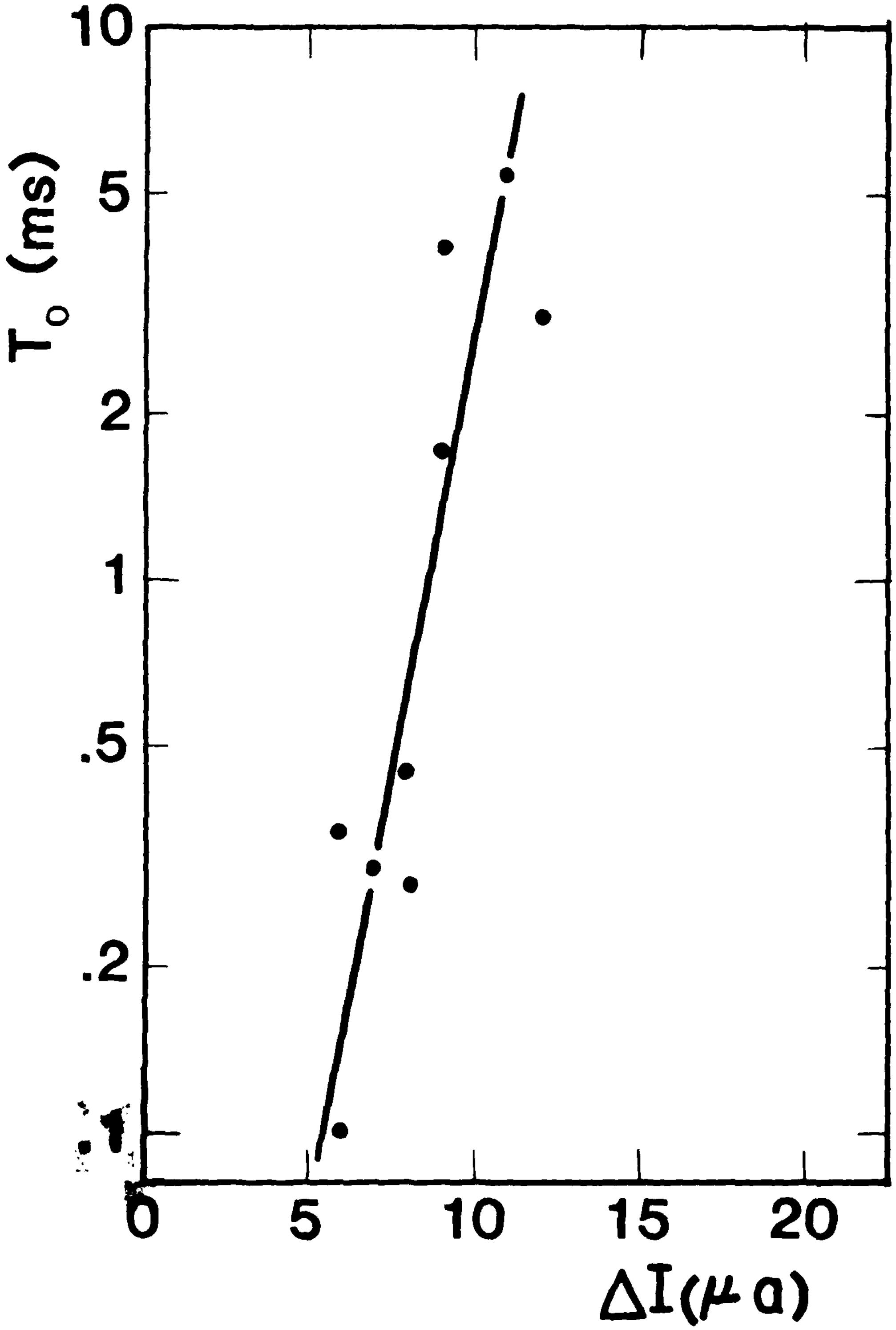

Figure 6. Effect of current width ΔI_g, between current steps, on lifetime τ_o.

and this will lead to a low frequency spectral density for the random force of

$$S_v(o) = \frac{1}{\pi} \frac{R_d^2}{R_{ef}} kT \qquad (5)$$

Here R_d is the dynamic resistance at the current step and R_{ef} is the effective resistance at the particular current step. Relation 5 shows that on the current steps where $R_d \rightarrow 0$, the fluctuations are small, as observed. In between the steps, the fluctuations can be large. We are in a regime where quantum tunneling is becoming important. This is substantiated by the strong dependence of the fluctuations on the bias conditions, a characteristic of tunneling processes.

Telegraph noise has been observed in other systems ranging from amorphous silicon[3] showing individual electro traps, to silicon inversion layers[4] with inte.face traps, to electron traps in small Josephson junctions,[5] and to SQUIDS;[6] our results refer to fluxon traps between current steps for bistable flux configurations.

We are currently investigating the driving mechanism that is responsible for this telegraph noise, whether it is thermal or quantum mechanical tunneling. The understanding of this noise is important in long junctions especially for applications where the junction is biased on a current step to produce very high frequency oscillations.

B. Chaotic and intermittent Behavior in Long Josephson Junctions

Equation 1 describes the behavior of a long Josephson junction when biased with d.c. or a.c. or both. It is a highly non-linear system (much more so than optical systems) and the fluxons are driven across the junctions by the bias force it is possible that under certain conditions instabilities can occur in the flow of these fluxons. It is a dissipative systems with a few degrees of freedom and turbulence in the flux flow is expected. Indeed there is a variety of theoretical papers showing that a Josephson junction is an excellent model for studying chaos and the critical behavior for the onset of chaos. These papers have been substantiated by many computer simulations, but there are very few experimental results on this subject. It is an interesting subject from the point of view of non-linear behavior but it is also important in showing us under which conditions the chaotic behavior of a device can be avoided and how to design around it.

In the presence of a d.c. voltage $V_{d.c.}$ the moving fluxon array in a junction induces internal oscillations at a frequency of

$$f = V_{d.c.}/\phi_o \tag{6}$$

This means that some power will be transmitted, depending on the power supplied by the d.c. superconducting current density $J_{s.d.c.}$ Hence a large current density will lead to a large transmitted power. The current step heights occurring in the d.c. I-V curve are a measure of the amplitudes of a.c. components induced in the junction.

There are many ways that chaotic behavior can be reached. For example there can be period doubling, quasiperiodicity, or intermittency leading to chaos. Chaotic intermittency can exist between the dynamic states corresponding to two consecutive current steps in the I-V characteristics.

Our situation with the long Josephson junction is ideal for investigating chaotic behavior. Because of the large number of current injection fingers, there is a large current flowing through the junction and hence there will be substantial radiation produced. The I-V curve has current steps. Hence, according to Goldhirsch et al[7] such characteristics can lead to a chaotic mode of intermittency where ordered, i.e. periodic solutions (current steps) are separated by chaotic bands with unstable solutions. The jumps between the steps appear to be random and they are determined by the strength of the instability of the solution corresponding to a given step. When the interstep gap is spanned by varying the bias current, the relative stability is changed.

We have probed such instabilities in our junctions by studying the effects on the I-V curve. Even though we had a limited bandwidth in our detection system (1 MHz), our results show that these instabilities can be considered as the approach to chaotic behavior. Our junctions are d.c. biased but the results are similar to r.f. driven junctions.[8] Actually long junctions with their high nonlinearity are expected to exhibit chaotic behavior even without external a.c. force. Our results are probably the first observations of this effect. In order to confirm our expectations of what our results mean, we are currently doing computer simulations. Also, we are modifying our detection system so as to be able to look at the broad spectrum of instabilities. The role of thermal noise[9] in these instabilities is very interesting[10] and it has not been investigated much. We are presently preparing experiments to extend such studies to the milli Kelvin temperature range.

C. Effect of Ultrasonics on Resonant Modes of Long Junctions

The results of our fluctuations studies (section A) show that pinning centers in the junction affect the characteristics of the device. We have also evidence for this in the gate - current I_g signal current I_s curve which shows that at relatively large signal currents I_s in the control line, the junction gate current I_g will not switch off entirely. To reduce the influence of fluxon pinning, we have attached an ultrasonic transducer to a long Josephson junction. In order to minimize cross-talk, the ultrasonic transducer was electrostatically shielded from the junction. The junction was irradiated with longitudinal ultrasound at 1 MHz in the longitudinal mode. As the sound level increased the self-induced current steps in the I-V characteristics disappeared. This is shown in figure 7. The ultrasound modulates the current flowing through the junction and it modifies the energy of the pinning traps in the junction. As the current is modulated there is an indirect effect on the flux-flow due to the Lorentz force acting on the fluxons. These preliminary results show that fluxon behavior is modified by ultrasound. It appears that at large ultrasound intensities the junction dynamics are affected with a suppression of the current steps. The phase locking of the fluxon motion inside the junction eventually breaks down. In this respect, this is similar to large intensity microwave irradiation. We are now investigating the interaction of sound with fluxons.

D. Boundary Effects on Fluctuations and Gain of Long Junctions

In order to have a large and fairly uniform current flowing through the long junction, current was injected by means of 8 fingers, as shown in figure 8. Most of the papers on this subject deal with direction introduction of current into the junction where it is forced by self-induced fields to the edges. The finger injection overcomes this problem. The presence of such fingers can lead to small pinning sites at each finger, especially for the fingers near the ends. Actually the edges can act like pinning sites for the fluxon structure. This is discussed in Likharev's[11] book where he shows that many small junctions in parallel would not be equivalent to a long junction, as far as gain goes. The current gain of a long Josephson junction can be written as

$$G = \frac{\Delta I_g}{\Delta I_g} \tag{7}$$

which is equivalent to $r_m/R_D + R_L$. Here R_L is the external load, R_D the dynamic resistance of the junction, and r_m its transresistance. It can be shown[12] that

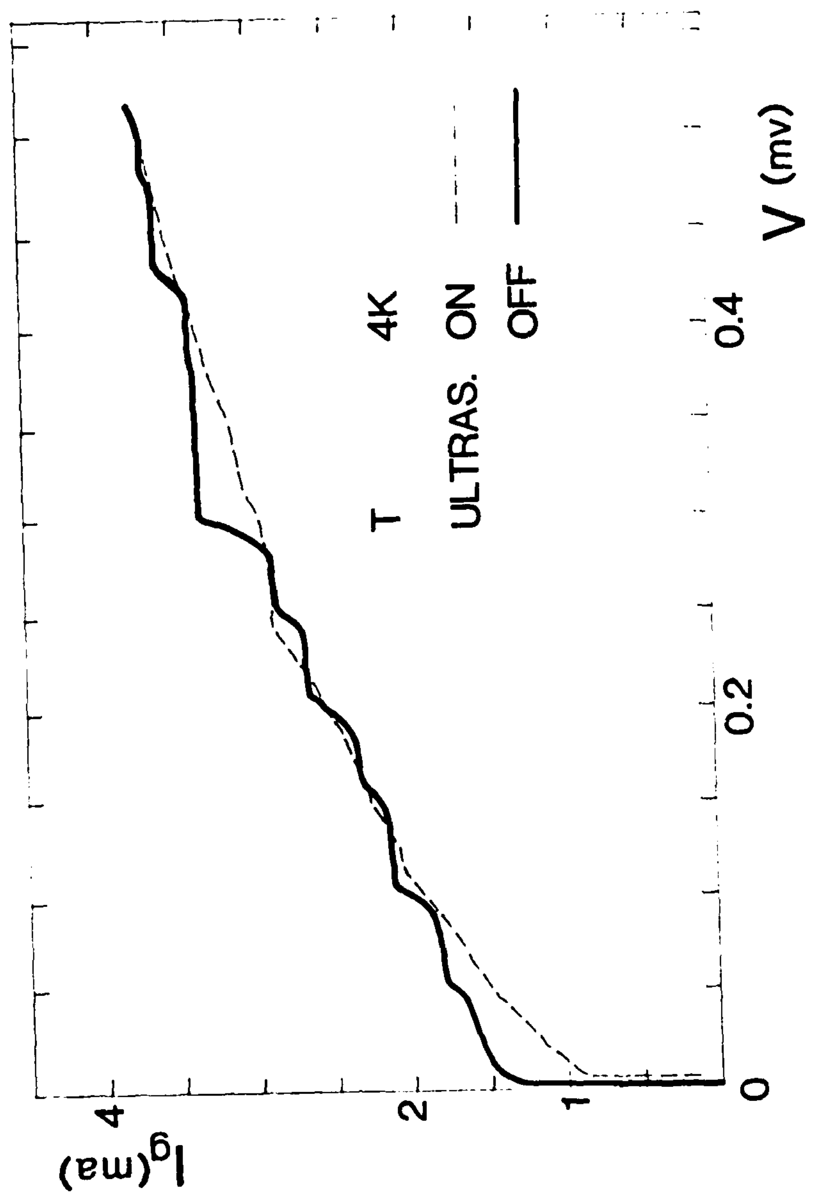

Figure 7. Effect of ultrasonics at 1 MHz on current steps of long junction.

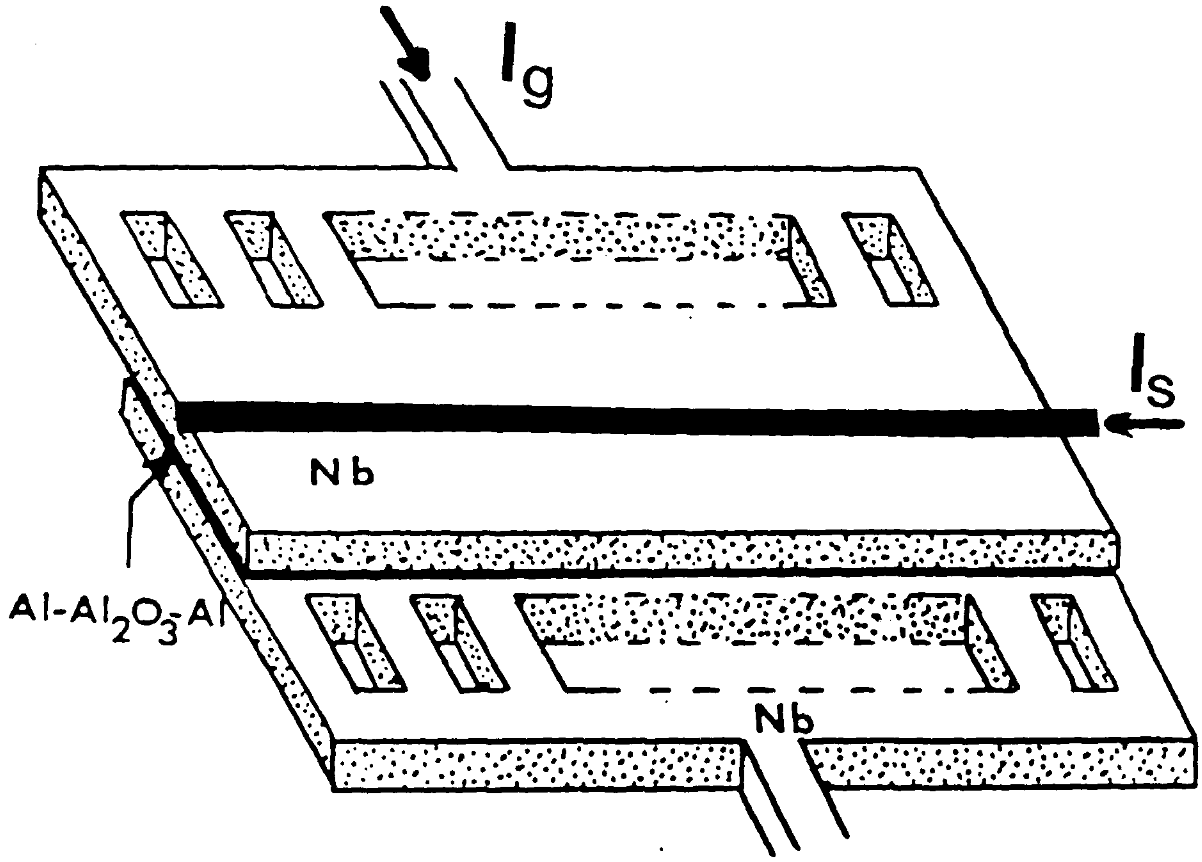

Figure 8. Geometry of long junction studied.

$$r_m = \mu_o \, d \, \bar{c}/w_s \qquad (8)$$

where $\bar{c}$ is the velocity of the electromagnetic wave in the junction, d the penetration depth of the magnetic field, μ_o the permeability, and w_s the width of the control line.

By reducing the width w_s an increase in gain is expected. Indeed the increase is a factor of 3 when we changed w_s from 65 μm to 19 μm. Figure 9 shows the transfer curve for such a junction with 8 equally space fingers. Figure 10 shows the transfer curve for a similar junction but with only 2 fingers left in the middle, the other 6 were removed in the fabrication. Such flat characteristics are expected[11] as the current injection location is removed from the edges. In order to compare the characteristics of the two junctions, figure 11 shows their I-V curves for different I_s. For the 8-finger junction, the current scale is 10 mA/cm while for the 2-finger junction it is 2 mA/cm. The current density for the 8-finger junction is 5×10^3 A/cm^2 and its β_c is 5. The 2-finger junction has the same resistance as the 8-finger one, but its critical current is less (since less current can be injected), and hence its β_c is ≤ 1. Indeed non-hysterisis behavior is observed for the junction whose I-V curve is shown in figure 11. Actually the I-V curve has some similarity with that for a semiconductor FET. It is interesting to note that the 8-finger junction has some current steps in large I_s. We have investigated the telegraph noise on these steps and its spectrum shows a Lorentzian distribution similar to the previous 8-finger junctions having hysterisis ($\beta_c > 1$). The highly damped junction ($\beta_c \leq 1$) does not show resonance effects and hence it does not display the previously observed telegraph noise. To emphasize the similarity of the long junction with a

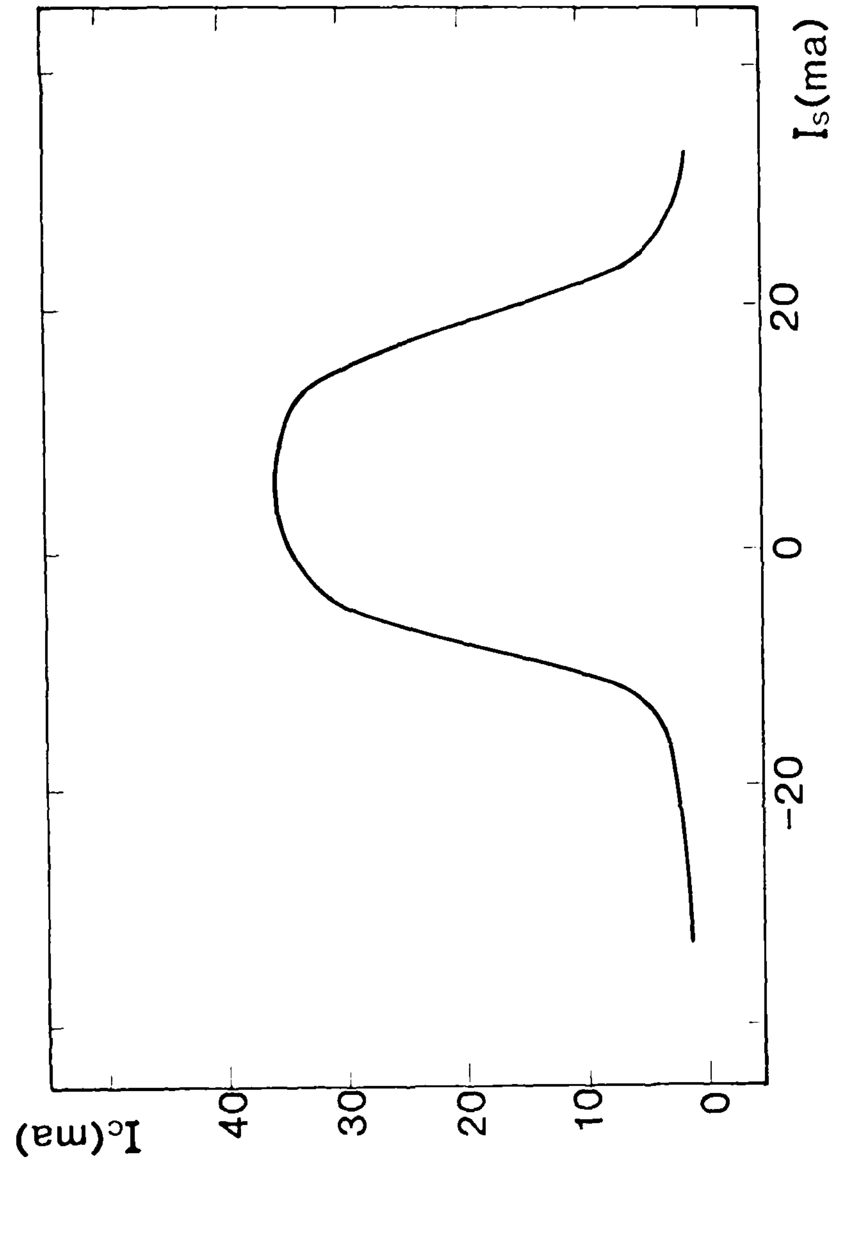

Figure 9. Gate current - control current curve for 8-finger.

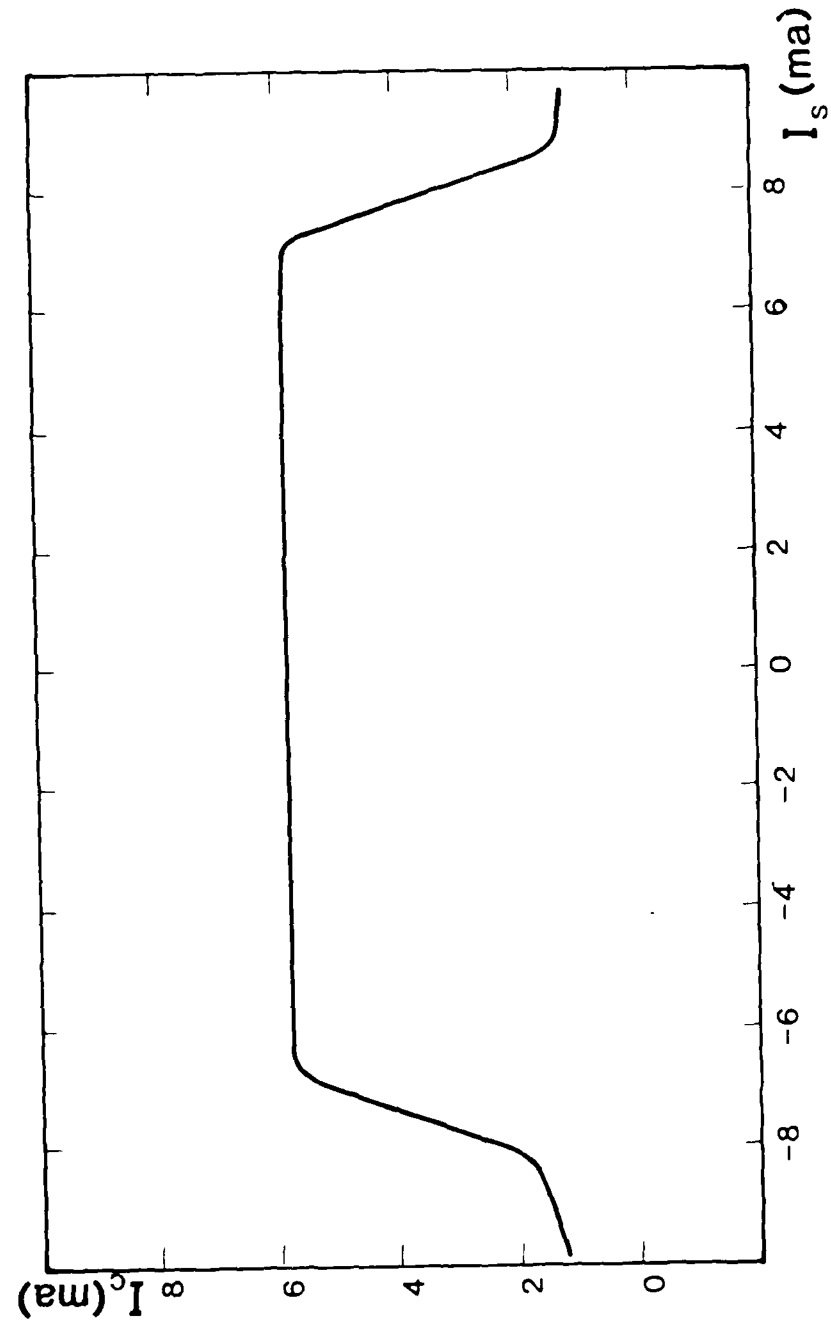

Figure 10. Gate current - control current curve for 2-finger junction.

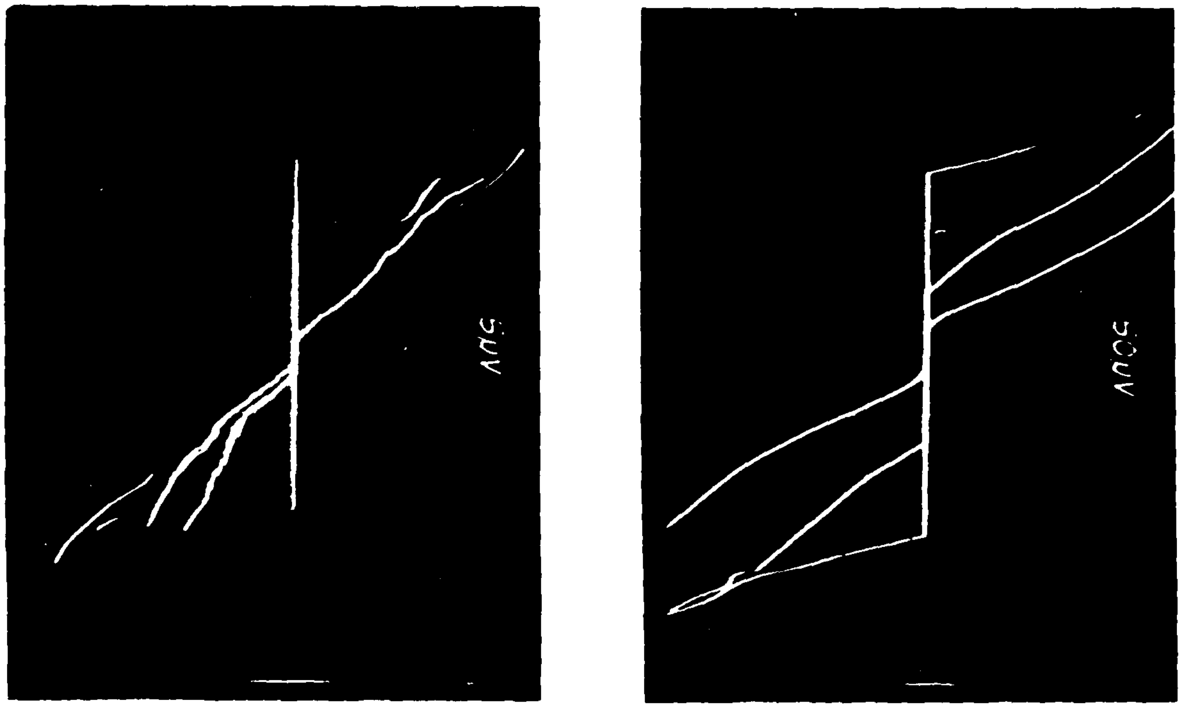

Figure 11. Current - voltage characteristics for different signal currents for 8-finger junction (left) and 2-finger junction (right).

semiconductor FET, figure 12 shows the voltage across the junction (the 2-finger one) as a function of signal current I_s for different I_g ranging from 1 mA to 5.8 mA. The vertical scale is 50 μm/cm.

These results show that for amplifier applications, we need long junctions with a large current density, a small β_c, and current injection fingers away from the ends.

We are presently investigating the ultimate noise limit of the 2-finger junction.

III. Proposed Experiments for Next Period

This project deals with fundamental aspects of fluxons in long Josephson junctions and with their application to devices. In continuing with these goals, the following experiments are proposed and planned for the next period of this grant.

A. Gain and Current Distribution in Long Josephson Junctions

Our design of injecting current into a junction by means of fingers allows us to have a large current which is fairly uniform in the junction and it also allows us to couple to the junction the control current I_s without serious problems of shielding I_s by the top and bottom electrodes. Indeed our long junctions have current gain.

The proposed experiments will deal with optimizing the location and the number of current injection fingers so as to have maximum gain. These experiments will be conducted on planar junctions as well as on edge junctions. Higher current densities are possible in edge junctions leading to higher gain and reduction in size of the device. Pinning at the junction ends will also be investigated.

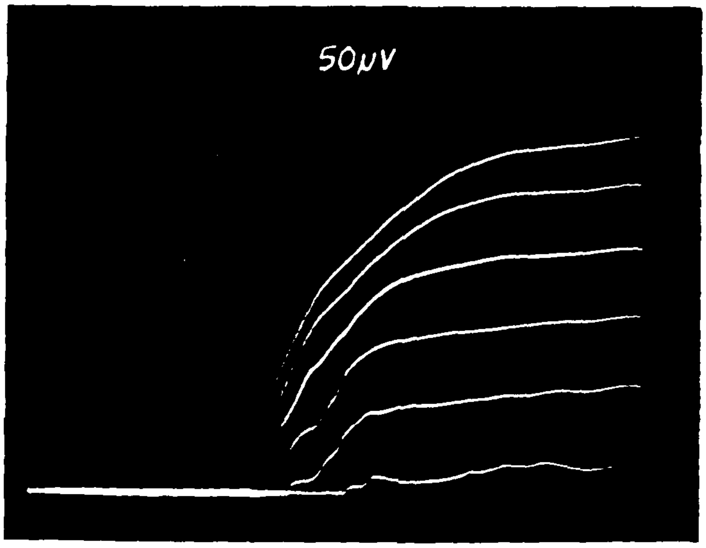

Figure 12. Junction voltage - signal current curve for different gate currents I_g.

B. Noise Characteristics of Long Josephson Junctions

Since a long Josephson junction can have smaller noise contributions than a small junction, we will pursue our study of noise limitation of such junctions. Of major interest is the measurement of flux flow noise for planar junctions and edge junctions. We propose to extend these studies to temperatures below 4 K so as to find out about the nature of the fluctuations.

The interest in the noise measurements has practical benefits for applications to devices, and in particular for amplifiers and oscillators. In the latter, the noise will affect the linewidth of the emitted radiation. Broad band noise and chaotic behavior in long junctions will be investigated down to milli Kelvin temperatures. Effects of chaos on quantum mechanics can be investigated.

C. Direct Measurement of Fluxon Distribution in Long Josephson Junction

Fluxon motion is usually determined from the I-V curves at the current steps. Recently a new technique was proposed for studying fluxons; it essentially consists of heating locally the junction with a very narrow laser beam[13] (or electron beam[14]) and destroying the fluxon to measure the resultant current change. This technique will be incorporated in our studies of current distribution in junctions. However, we also propose non-destructive methods based on direct measurements and magnetic resonance to investigate fluxon behavior. The direct method consists of coupling a SQUID magnetometer to a long junction and thus to follow the motion (when it is slow) of the fluxons. This is an extension of a technique[15] used to study flux-flow noise.

The other method consists of doing magnetic resonance inside the junction with the r.f. power provided by the electromagnetic waves inside the junction. From equation 6, the frequency can be selected by varying the voltage across the junction. Gadolinium impurities will be introduced into the barrier (at a level of ~ 100 p.p.m.). EPR will then be performed on these spins in essentially zero field (the lines are split by the large crystal field). Also, the junction has niobium nuclei on which it is relatively easy to do NQR. In both types of resonance, the fluxons will affect the linewidth. These studies are an extension of techniques used to study vortices in type II superconductors.[16]

D. Quantum Tunneling

We propose to study quantum tunneling effects in long Josephson junctions at temperatures such that the thermal activation processes become small compared to tunneling. The cross-over temperature from one regime to the other is given by

$$T_Q = \frac{\hbar\,\omega_o}{2\pi\,k} \qquad (9)$$

where ω_o is the plasma frequency $(2\,e\,I_c/\hbar C)^{1/2}$ for a typical junction of $\sim 10^3$ A/cm^2, this will occur around |·| K. Such a study will also tell us about the effects of dissipation[17] on quantum tunneling. The junctions will be cooled to temperatures below 1 K by means of a ^3He-^4He dilution refrigerator and the switching of the junction to the voltage state will be investigated.

References

(1) F.N. Hooge, Phys. Lett. 29A, 139 (1969).

(2) C.T. Rogers and R.A. Buhrman, IEEE Trans. on Magn. MAG-19, 453 (1983).
H. Mikoshiba, IEEE Trans. on Ed. Dev. Ed-29, 965 (1982).

(3) C.T. Rogers, R.A. Buhrman, H. Kroger, and L.N. Smith, Appl. Phys. Lett. 49, 1107 (1986).

(4) K.S. Ralls, W.J. Shocpol, L.D. Jachel, R.E. Howard, L.A. Fetter, R.W. Epworth, and D.M. Tennant, Phys. Rev. Lett. 52, 228 (1984).

(5) C.T. Rogergs and R.A. Buhrman, Phys. Rev. Lett. 55, 859 (1985)

(6) R.T. Wakai and D.J. Van Harlingen, Appl. Phys. Lett. 49, 593 [illegible]

(7) I. Goldhirsch, Y. Imry, G. Wasserman, and E. Ben-Jacob, Phys. Rev. B 29, 1218 (1984).

(8) Q. Hu, J.H. Free, M. Iansiti, O. Liengme, and M. Tinkham, IEEE Trans. [illegible] Magn. MAG-21, 590 (1985).

(9) D.C. Cronemeyer, C.C. Chi, A. Davidson, and N.F. Pedersen, Phys. Rev. B 31, 2667 (1985).

(10) C. Moldeke, R. Gross, M. Bauer, G. Reiner, and H. Seifert, J. of Low Temp. Phys. 64, 235 (1986).

(11) K.K. Likharev, "Dynamics of Josephson Junctions and Circuits". Gordon and Breach Science Publishers, 1986, p. 250.

(12) T. Magatsuma, K. Enpuku, H. Imakura, and K. Yoshida, Jap. J. of Appl. Phys. 24, L599 (1985).

(13) J.R. Lhota, M. Scheuermann, P.K. Kuo, and J.T. Chen, IEEE Trans. on Magn., MAG-19, 1024 (1983).

(14) J. Bosch, R. Gross, M. Koyanagi, and R.P. Heubener, Phys. Rev. Lett. 54, 1448 (1985).

(15) W.J. Yeh and Y.H. Kao, Phys. Rev. Lett. 53, 1590 (1984).

(16) J.M. Delrieu and J.M. Winter, Solid State Com. 4, 545 (1966)

J.M. Delrieu, J. Phys. F. Metal Phys. 3, 893 (1973).

(17) S. Washburn, R.A. Webb, R.F. Voss, and S.M. Farris, Phys. Rev. Lett. 54, 2712 (1985).

IV. Publications

(1) Voltage Fluctuations in Long Josephson Junctions, B.S. Han, B. Lee, O.G. Symko, and D.J. Zheng, in preparation.

(2) Current Distribution and Gain of Long Josephson Junctions, B. Lee and O.G. Symko, in preparation.

(3) A-D Concepts, I.R. Detection, and Long Josephson Junctions, O.G. Symko, Presented at Air Force Applications of Cryoelectronics Meeting, October, 1986, Wright-Patterson.

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